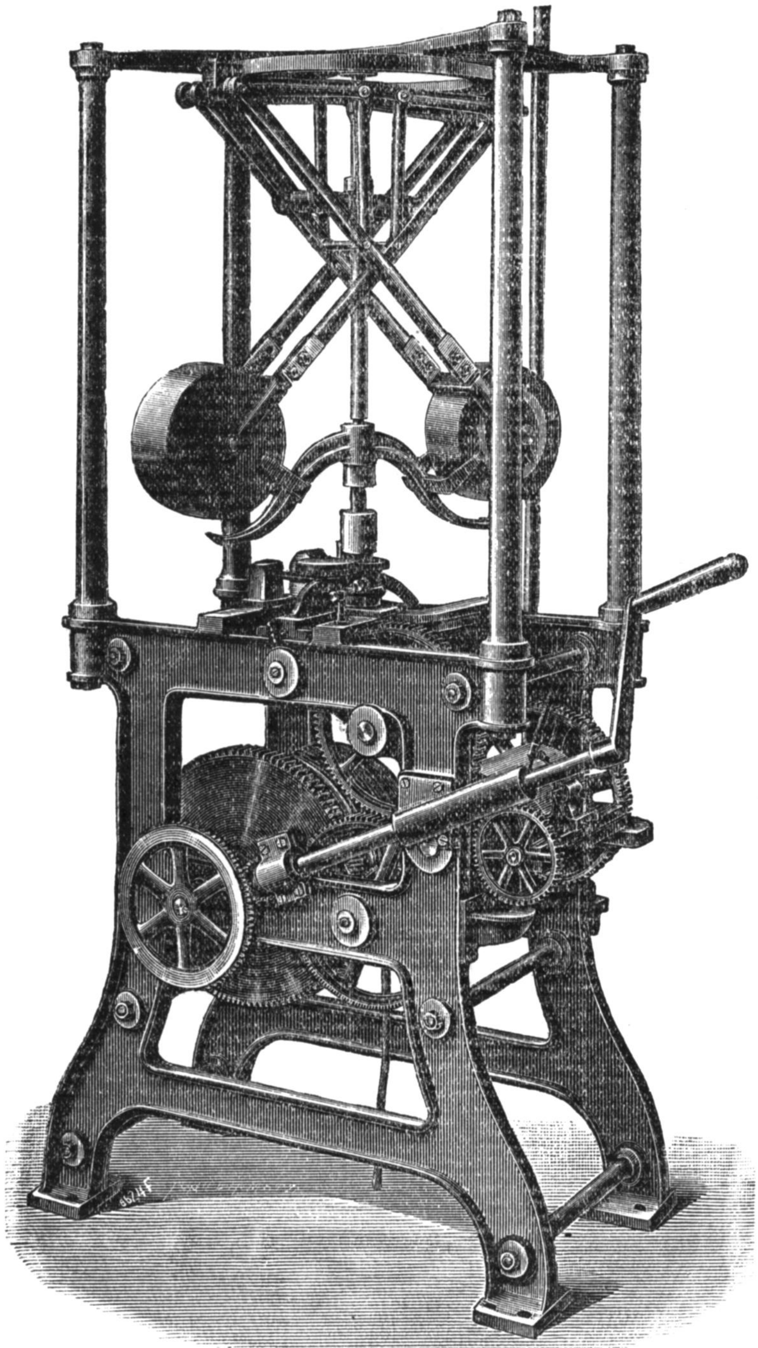


DRIVING-CLOCK OF THE THIRTY-SIX-INCH EQUATORIAL.
(By the courtesy of *Engineering*.)

form of the relation might be given, but the new value of *Mercury's* mass requires confirmation.

ARLINGTON AVENUE, RIVERSIDE, CAL., November, 1889.

N. B.—This note was already in type when the author learned from the *Sidereal Messenger* for December, 1889, (p. 471), that a note on the same subject had been printed in the *American Journal of Science* for November last. It was, however, too late to withdraw the article.

A NEW AND SIMPLE FORM OF ELECTRIC CONTROL FOR EQUATORIAL DRIVING-CLOCKS.

BY JAMES E. KEELER.

It is well known that the driving-clocks of equatorial telescopes, which demand a continuous motion, cannot be made to run with the uniform rate which is characteristic of a good pendulum clock; hence, methods are sought for regulating a continuous motion by means of a pendulum. Devices for effecting this mechanically have not been successful, where great accuracy is required. In such arrangements extra work is necessarily thrown upon the pendulum, which is prevented from swinging freely, and is then no longer isochronous. By means of electricity, however, the control can be effected without detrimental reaction on the pendulum.

For a description of the ingenious devices which have been invented for controlling driving-clocks electrically, the reader is referred to a pamphlet by Sir HOWARD GRUBB,* describing four different systems which have been tried or are actually in use.

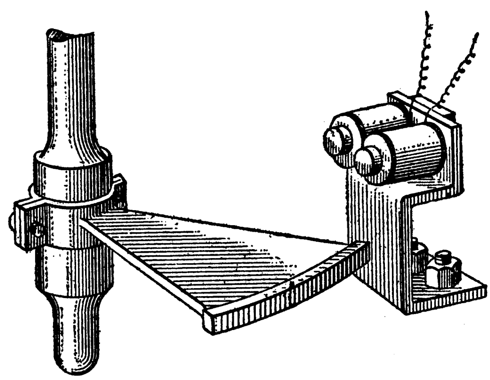
The driving-clock of the 36-inch equatorial of the Lick Observatory is of the same form as the smaller driving-clocks by WARNER & SWASEY, with a few modifications, made necessary by its unusual size and weight. The governor-balls weigh sixty pounds each, and their centers of figure and gravity are not coincident; so that the regulation for rate may be effected by turning the balls on their axes. The vertical shaft of the governor rotates once a second. One of the clock-arbors, which rotates in one minute, has been converted into a chonograph by the makers, an extremely convenient arrangement, since it gives a means of studying the performance of the machinery by an astronomical clock, without direct reference to the heavens.

* On the Latest Improvements in the Clock-driving Apparatus of Astronomical Telescopes. By Sir HOWARD GRUBB, Inst. of Mech. Eng., London, 1888.

The driving-clock is of excellent workmanship, and its rate is sufficiently uniform for micrometer measurements and all the ordinary purposes of an equatorial. For photographic and spectroscopic work the makers provided an electric control, which, on trial, was found not to work satisfactorily, as it communicated a jar to the telescope.

In the *Scientific American* for November 10, 1888, I described a simple form of electric control which was designed to remedy this defect. As the same device, with slight modifications, is still in use, I quote in part the description there given:

"A soft iron sector, subtending an angle of 36°, and having a radius of six inches, is clamped to the vertical axis of the governor, and rotates in a horizontal plane. The sector passes very close to the poles of an electro-magnet (part of the old control), which is mounted on a slightly elastic standard of steel.



ORIGINAL DESIGN OF CONTROL.
(By the courtesy of *The Scientific American*.)

At every second a strong current is sent through the coils of this magnet by means of a standard clock, the circuit being closed, as in the case of the old control, by the relay points of the chronograph attached to the driving-clock. The driving-clock is set so as to run a little too fast, and when the governor is started the sector continually gains upon the click of the chronograph until it reaches the magnet of the control, when the friction produced by the attraction of the latter prevents any further acceleration, and the governor will rotate in exactly one second by the standard clock as long as the control is in operation.

"The elasticity of the support on which the electro-magnet is mounted plays an important part in the proper working of the control. When the sector passes at the exact instant of the passage of the current, the magnet springs in toward the sector and comes in actual contact with it, very greatly increasing the friction, while the

passage of the sector at any other instant meets with no resistance, the magnet being slightly withdrawn by its support.

"The current used with the control is obtained from a battery of twenty* gravity cells, employed during the daytime in transmitting time signals to San José. As the signals are not sent at night, the battery is then connected with the control by turning a switch. With this control no shock is communicated to the telescope, and the image of a star is steady."

The apparatus described above was used for some time, and found to be satisfactory in every respect but one; it was not quite powerful enough to hold the governor with certainty within the greatest range of accidental variation of rate. The radius of the sector, six inches, had been chosen at random, without any guide to indicate the proper dimensions. Another sector was, therefore, made, with a radius of 8½ inches, and put on in place of the old one, the apparatus being otherwise exactly as before. The control then worked perfectly, and has been used ever since with entire satisfaction.

Professor Howe, of Denver, while visiting the Lick Observatory last winter, suggested an improvement which is apparently an excellent one, although circumstances do not admit of its application to the 36-inch equatorial, and I have represented it in the accompanying diagram. (See plate.) With the existing arrangement, some little attention is necessary to get the sector in the proper part of its orbit when the current passes. The governor is first started at full speed, and then, if necessary, slowed down by hand until the sector falls within range of the magnet at the beat of the chronograph; otherwise much time would be consumed in waiting for the governor to gain the necessary distance. If the magnet were movable about the axis of the governor, it could at once be set to the proper position after the governor had attained its maximum speed, and held there by a clamp. Such an arrangement is shown in the diagram. For the sake of clearness, the wires bearing the current are not shown beyond the control magnet, but it would evidently be very easy to lead the current through the central pivot, the connecting-bar and the circular track for the clamp, leaving the arm free to rotate in either direction. A further description of the diagram seems to be unnecessary.

This control may, at first view, appear to be somewhat "brutal" in principle, and liable to produce vibrations in the telescope; but

* Eighteen cells are in use at present (November, 1889).

experience shows that a practically uniform motion is attained, and a star bisected by a micrometer thread in the field of the telescope does not show the slightest evidence of tremor at the passage of the sector. In a very short time after starting the driving-clock the sector settles down into a certain position relative to the magnet, which it preserves as long as the current passes. This position is found to be a little *behind* the magnet, so that the circuit is broken before the full retarding force comes into play. It will be noticed that, as in other effective controls, the friction is applied gradually, and nearly in proportion to the amount of the error to be corrected. In the particular case of the Lick Observatory driving-clock the action is necessarily vigorous, on account of the great momentum of the governor. The amount of the friction is easily regulated by varying the battery power.

A photographic reproduction of part of a chronograph sheet (reduced to about one-half) is shown under the diagram, and illustrates the action of the control better than any description. It contains no error greater than $0^{s}.01$. It may be noted that since the same clock is employed to operate the control and to record on the chronograph, the seconds columns on the sheet are strictly parallel to the axis of the chronograph barrel, no matter what the rate of the standard clock may be, for the angular velocities of the pendulum axis and chronograph barrel are always as 60 : 1, and the governor rotates once for each beat of the pen. When different clocks are employed for controlling and for marking, the columns are inclined by an amount depending upon the difference of the rates of the two clocks, an amount too small, however, in any ordinary case, to be appreciable by the eye.

It has been shown above that the governor shaft of the driving-clock can be made to rotate with uniform velocity in one second by a standard astronomical clock. Whether the polar axis will rotate with a correspondingly uniform motion will depend upon the perfection of the gear-cutting in the intermediate parts of the train. Two of the controls described by Sir HOWARD GBUBB have the advantage of applying the necessary corrections close to the screw which drives the great wheel on the polar axis, and thus avoiding the errors of several pairs of gears. For long exposures in photography, particularly with very large telescopes, correction by hand* is imperative,

*In the 36-inch refractor of this Observatory, and the 5-foot reflector of Mr. COMMON, this correction is not made by moving the telescope, but by moving the photographic plate, which is mounted on double slides and moved accurately by fine screws.

since no automatic contrivance can allow for the errors caused by change of refraction and flexure, and absolutely uniform rotation of the polar axis is of less consequence. It is sufficient if the errors of the clock-work are small, and are not cumulative, as they are apt to be without control by a standard clock.

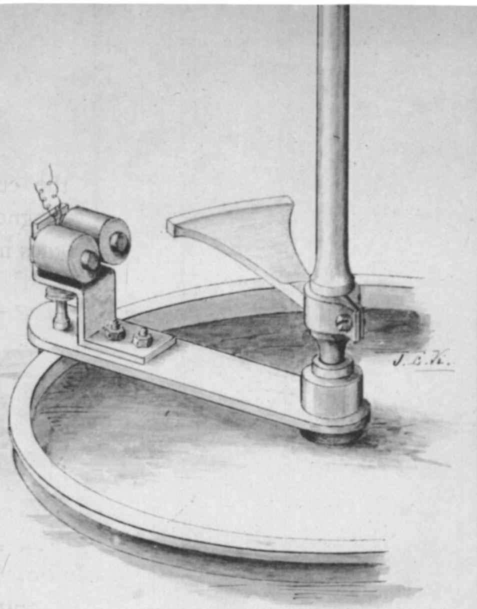
It is not easy to say how readily this control could be applied to smaller instruments. The governors of driving-clocks seldom rotate so slowly as once a second, but the control could evidently be applied to any shaft rotating in an integral part of a second. The sector might also require to be balanced by a counterpoise, or two diametrically opposite sectors and magnets could be used. For large telescopes, experience at this Observatory has shown that the control is perfectly efficient.

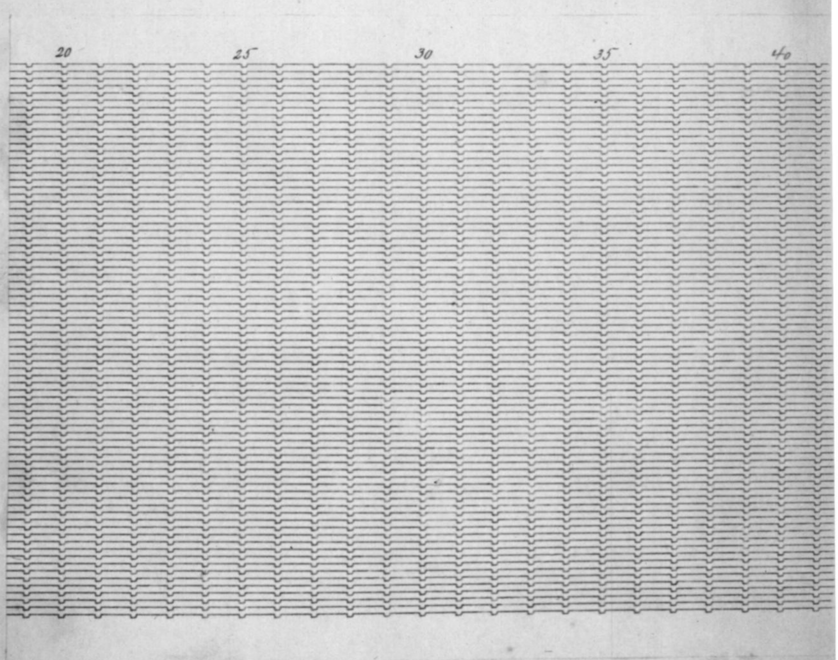
A method for bringing the control of the Lick telescope rapidly into action, and applicable under existing arrangements, occurred independently to Professor HOLDEN and myself, and will be given a trial. Four equidistant sectors, each consisting of a block of soft iron, are enclosed between two circular discs of thin sheet brass, the axis of the governor passing through the center. The sector nearest to the magnet will then come first into action, the others being inoperative, and the governor will never have to gain more than one-fourth of a revolution; the chances are that a gain of less than one-fourth will be required.

DETERMINATION OF THE RELATION BETWEEN THE EXPOSURE-TIME AND THE CONSEQUENT BLACKENING OF A PHOTOGRAPHIC FILM.

BY ARMIN O. LEUSCHNER.

For some time past it has been the custom at the Lick Observatory to standardize photographic plates on which photographs of celestial objects had been secured. The process of standardizing a plate consists in exposing some portion of it, previously protected against the light of the object, to the light of a standard-lamp through a small square aperture. On development the plate will show a more or less dark square, due to the light of the lamp. In all cases a series of squares is secured on the plates, the times of exposure being either 1^s, 5^s, 10^s, 20^s, 30^s, etc., or 1^s, 2^s, 4^s, 8^s, 16^s, etc., according to cir-

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